

Response of Multi-strip Multi-gap Resistive Plate Chamber

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ABSTRACT: A prototype of Multi-strip Multi-gap Resistive Plate chamber (MMRPC) with active area $40\text{ cm} \times 20\text{ cm}$ has been developed at SINP, Kolkata. Detailed response of the developed detector was studied with the pulsed electron beam from ELBE at Helmholtz-Zentrum Dresden-Rossendorf. In this report the response of SINP developed MMRPC with different controlling parameters is described in details. The obtained time resolution (σ_t) of the detector after slew correction was $91.5 \pm 3\text{ ps}$. Position resolution measured along (σ_x) and across (σ_y) the strip was $2.8 \pm 0.6\text{ cm}$ and 0.58 cm , respectively. The measured absolute efficiency of the detector for minimum ionizing particle like electron was $95.8 \pm 1.3\%$. Better timing resolution of the detector can be achieved by restricting the events to a single strip. The response of the detector was mainly in avalanche mode but a few percentage of streamer mode response was also observed. A comparison of the response of these two modes with trigger rate was studied.

KEYWORDS: Multi-strip Multi-gap Resistive Plate Chamber(MMRPC); Gas detector; Fast timing.

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1. Introduction

Three decades ago the Resistive Plate Chamber (RPC) [1, 2] was invented to overcome several problems of parallel plate chambers. Unlike parallel plate chambers, electrodes of RPCs are made of resistive material like Bakelite or glass. This has the effect that only a limited part of the electrode is discharged during the passage of an ionizing particle with subsequent avalanches or streamers, while the rest of the electrode remains unchanged. To improve timing resolution, Multi-gap Resistive Plate Chamber [3, 4] (MRPC) is an intelligent modification of an RPC by increasing the electric field across the gap and creating thinner layers of gas gap by inserting (electro-statically) floating glasses between anode and cathode. Time resolution better than 50 ps σ at 99% for Minimum Ionizing Particle (MIPs) can be achieved by operating a MRPC detector in avalanche mode. Further, segmented structure in readout strips design makes the position resolution of MRPC as good as 0.5 mm[5]. MRPCs are, thus, high granularity, high-resolution inexpensive TOF system (compared to standard scintillator with PMTs) appropriate for large scale applications. This includes both fundamental research in particle physics large scale experiments i.e, STAR[6, 7], HARP[8], ALICE[9, 10], astrophysics [11], cosmology [12], nuclear physics HADES[13, 14], FOPI[15, 16, 17], and applied research in medical imaging (cost effective Positron Emission Tomography) [18, 19], security purpose like cosmic muon tomography [20], climate change[21] etc. The response of such detector under irradiation by the γ -ray [22] and neutrons has not been studied in details [24, 23, 22, 25]. In order to explore in this direction a prototype of Multi-strip Multi-gap Resistive Plate Chamber (MMRPC) has been developed at SINP, Kolkata. In first stage of development, the design was focused on the feasibility study of the MRPC as an active part of high energy, high efficiency neutron TOF. The response of the MMRPC detector using γ and cosmic muon was extensively studied at SINP, laboratory , [22]. Later, the detector was taken to the electron linac ELBE at Helmholtz-Zentrum Dresden-Rossendorf, Germany to study its electron response. The optimum operating condition (w.r.t efficiency, time resolution, position resolution, etc.) was studied. In the following, the response of our newly developed MMRPC detector for electrons will be discussed in details.

2. Detector construction and design details

As a first step, we have developed a prototype of double stack, four gas gap glass MMRPC of size $40\text{ cm} \times 20\text{ cm}$ with segmented anode strip. Figure 1 shows the cross-section view of the developed MMRPC. The anode strip is made of PCB with thin layer of gold coating and has nine anode read out strips with two strips at the edges grounded via 50 ohm resistance. This was designed by a group of scientists at SINP and manufactured by local workshop of Kolkata. The anode strip size is 2.0 cm wide and 40 cm long. Each strip are read out at both the end. Thus for this MMRPC, in total eighteen readout-signals are there. Figure 2 shows the anode strips of the MMRPC detector. The cathode plates are made by introducing a thin layer of conducting material on 1 mm thick float glass. Negative high voltage is supplied to the cathode whereas the anode is kept at the ground potential. Four uniform and symmetric gas gaps are made between two cathode plates. Fishing lines (0.3 mm diameter) are used as spacer between glass plates. Thus, two sets of 1 mm thick floating glass and 0.3 mm gas gap act as dielectric material between the cathode and anode plates. This detector structure is housed in an aluminum chamber which was designed and build at workshop of SINP, kolkata [22]. A custom built gas system[26] was used where four gases can be mixed and delivered to four RPCs. A moisture meter is also available for monitoring of the gases. The gas system with the mass flow controller produce a gaseous mixture of R134a ($\text{C}_2\text{H}_2\text{F}_4$), Sulfur hexafluoride (SF_6), Isobutene (ISO- C_4H_{10}) in the ratio of 85:6.3:8.5 at normal atmospheric pressure condition used as the counting gas within the MMRPC detector. The detector is flushed with the gas mixture in every ~ 8 hrs.

2.1 Experimental Set-up

Electron response of the developed MMRPC detector was studied at the radiation physics cave of ELBE, Dresden, Germany

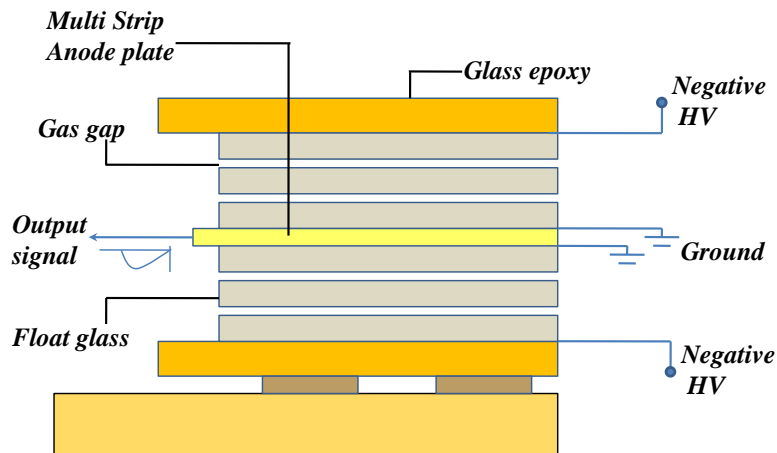


Figure 1. Cross-section view of developed Multi-strip Multi-gap Resistive Plate Chamber.

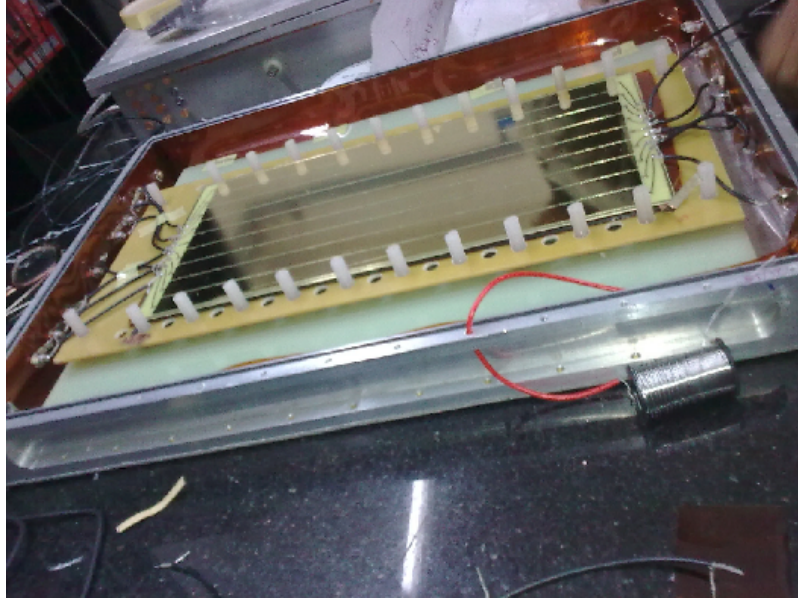


Figure 2. Photograph of Multi-strip Multi-gap Resistive Plate Chamber with segmented anode strip.



Figure 3. Photograph of the experimental set-up for studying the electron response of MMRPC at ELBE.

For detailed study of the electron response of the SINP prototype the detector was irradiated with the electron beam of 29 MeV from Electron Linac with high Brilliance and low Emittance (ELBE) facility at Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany. The radiation source ELBE is based on a super conducting electron linac delivering electron beams in the energy range of 10 - 40 MeV. The accelerator produces a quasi-continuous electron beam with micro-pulse

repetitive rate ranging from 1Hz to 260 MHz. At a beam current of 1 mA the charge of electron bunch can be varied from 1 fC up to 77 pC by changing the source current at the pulse injector i.e. the 250 kV electron gun. Four cavities are operated in a nominal accelerating gradient of 10 MeV/m (10 MeV energy gain per cavity). One or more special aluminum foils are introduced in the optical path between two accelerator cavities. This leads to the production of single electron bunch of pulse width less than 10 ps[28]. This short micro-pulse duration makes it very attractive to use the RF signal of ELBE as time reference for time measurement.

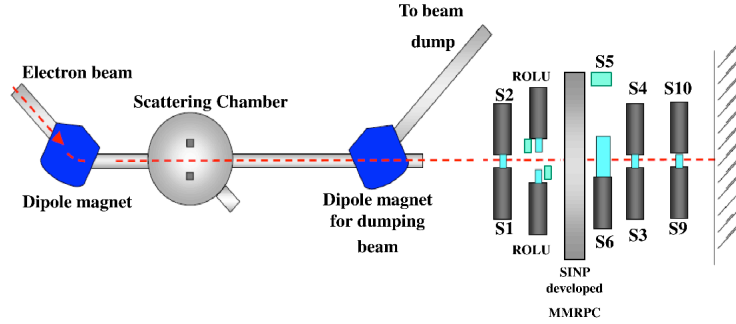


Figure 4. Block diagram of the experimental setup for studying the electron response of MMRPC. The pulsed electron beam, shown by dashed line, passes through the air column of 41 cm and then bombards on the set-up.

The electron energy was chosen to be 29 MeV with pulse width less than 10 ps. The beam was operated in single-electron per bunch mode [28] and was allowed to impinge on the test set-up through a 40 micrometer thick Beryllium window. Figure 3 shows a photograph of the experimental set-up at the radiation physics Cave at ELBE during this experiment. The geometry of the experimental set-up is shown in Figure 4. The pulsed electron beam (shown by dashed line in figure 3) passes through the air column of 41 cm before bombarding the set-up. The setup consists of several scintillators on the path of electron beam. Three scintillators (BICRON BC-408) were read out by a pair of 2 inch Photo Multiplier Tubes (XP2020) hence delivering signals from S1/S2, S3/S4 and S9/S10. In between the scintillator S1/S2 and SINP MMRPC detector (Figure 2 and 3) there was an active collimator (ROLU) which consisted of four plastic scintillators, each read out by a PMT. There was another plastic scintillator S6, placed between MMRPC and S3/S4. The beam profile was obtained using a plastic scintillator S5 placed after the MMRPC detector. Both MMRPC and this plastic scintillator can be moved using a remote controlled motor to scan both in horizontal and in vertical direction. The time information of the scintillators were extracted using constant fraction discriminator (ORTEC CF 8000). FOPI cards[29] were used as the Front End

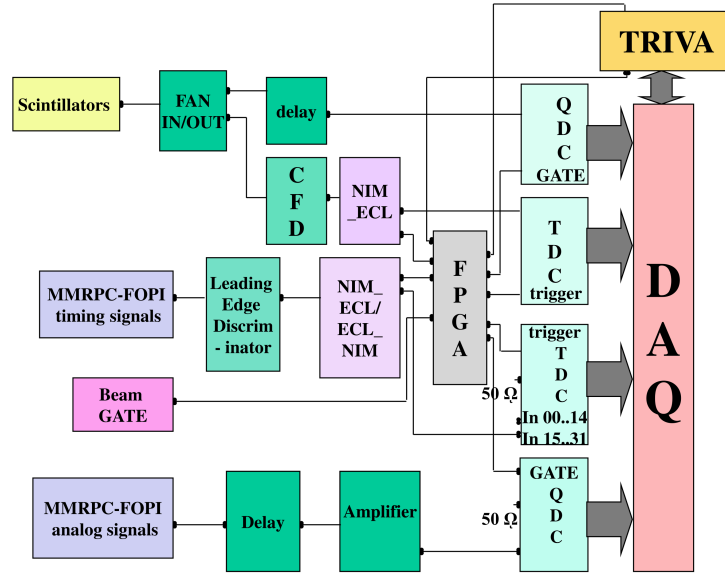


Figure 5. Block diagram of the electronics used for the processing the timing and analog signals of MMRPC and scintillators.

Electronics (FEE) of the MMRPC. The timing signals from the FEE card were shaped using leading edge discriminator (Philips octal Discriminator 710). A logical AND of the timing signals from the scintillators S1, S2, S6 and the RF provides the master trigger logic for the DAQ system. The MMRPC analog signals after being delayed (125 ns) through Aircell 5 patch delay were digitized with a CAEN QDC V965. The digitized amplitude signals were used for the time-slewing (walk) correction. The essential component of the DAQ is a CAEN 32 channel multi-hit TDC of type (V1290A) with a least significant bit (LSB) size of 25 ps. The Multi-Branch System (MBS)[30] was used for the data acquisition (DAQ). Figure 5 shows the block diagram of the electronics used for the processing and acquiring the signals from the MMRPC and the scintillators detectors.

To find the optimum operational condition of the prototype, the detector efficiency and time resolution were studied as a function of the applied high voltage using a beam with a flux of 50 Hz/cm². During this procedure the beam was focused on a single strip of MMRPC. In subsequent steps, the same procedure was repeated with increased trigger rate of the beam up to 1000 Hz in steps of 200Hz. Measurements were also performed with the beam spot focused on each of the other individual strips of MMRPC. All these measurements were performed with the beam spot positioned at the middle along the length of individual strips. The beam spot was further moved along the strip to the edges for making position measurements.

3. Analysis and Results

Figure 6 shows a plot of dark current against bias voltage. The beam profile was scanned with the help of scintillator detector mounted on a linear step motor drive. The scintillator detector was moved horizontally to identify the center of the beam.

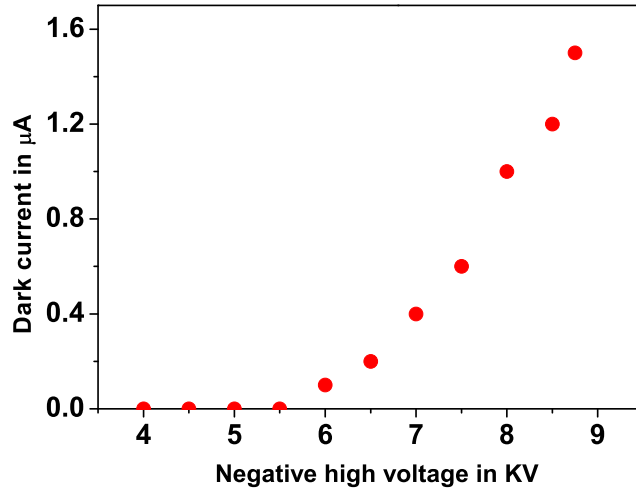


Figure 6. Plot of dark current against bias voltage of MMRPC.

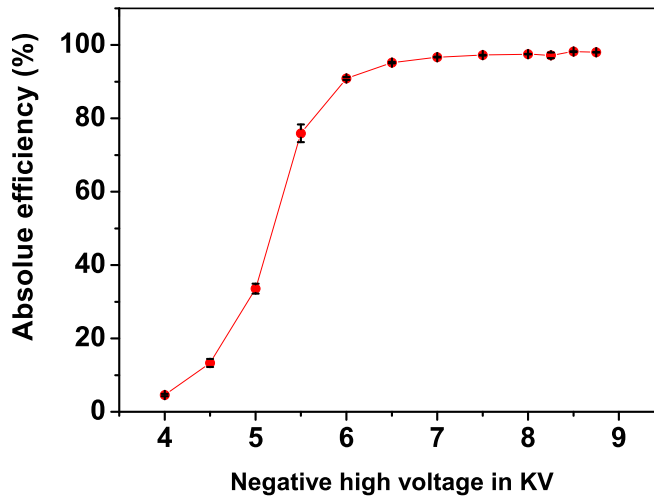


Figure 7. Plot of absolute efficiency against bias voltage of MMRPC.

A vertical scan was performed keeping the horizontal position of the detector fixed at beam center. The measured FWHM of the beam was ~ 2.5 cm. The beam profile being larger than the strip width, absolute efficiency of the MMRPC detector was determined using the following logic. The beam spot was focused on strip number 4. A valid event or “good events” of the particular strip of MMRPC was considered when a strip had a valid event from the TDCs at the two ends of that particular anode strip. Now, the dimension of the beam spot clearly shows that any one of neighboring three strips can be fired for a particular event. Hence, “good events” are those which

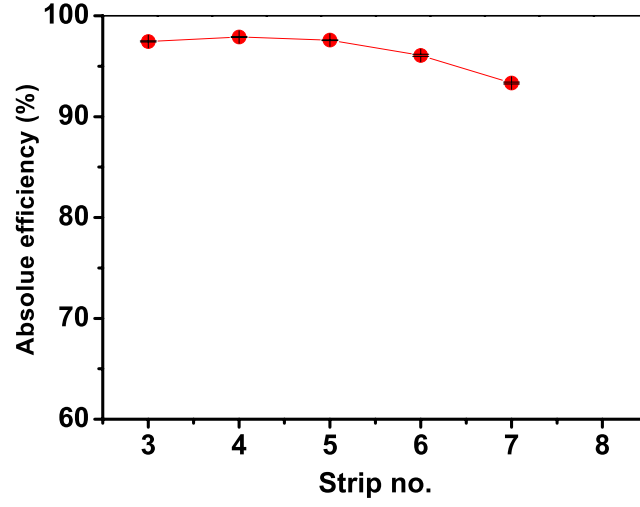


Figure 8. Variation of absolute efficiency against the strip number of MMRPC.

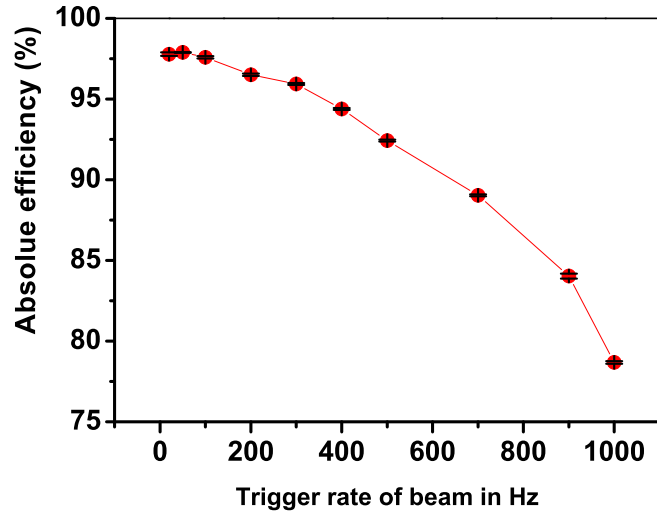


Figure 9. Variation of absolute efficiency against the trigger rate for fixed bias voltage.

have good signals either in strip 4 or its neighboring strip (i.e, strip 3 and 5). Hence, the absolute efficiency of our developed MMRPC can be defined as the ratio of the number of “good events ” or valid events of MMRPC to number of events triggered in that particular time interval. Figure 7, 8 and 9 show the plot of the absolute efficiency against the bias voltage of MMRPC, strip number of MMRPC and triggering rate of the incident beam, respectively. In this analysis, the absolute efficiency of MMRPC reaches 95.8 ± 1.3 % at bias voltage greater than 6.5 KV. A sufficiently long plateau has been observed allowing for safe detector operation. Therefore, a high voltage of 7.5 kV

was applied to the Cathode of the detector for further investigations. It is also visible that efficiency of the detector decreases with increasing trigger rate. In the plot of the absolute efficiency against strip number (Figure 8) almost an uniform efficiency of the detector was observed.

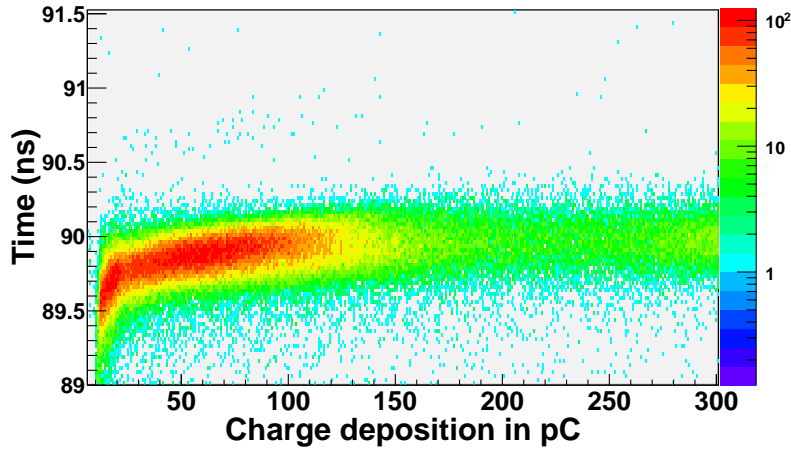


Figure 10. Two dimensional plot (without any slew correction) for the time distribution of MMRPC against the charge deposited in the strip.

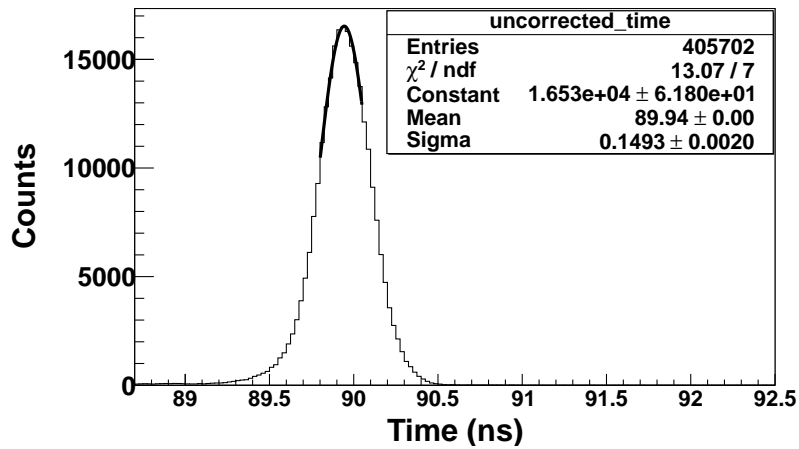


Figure 11. Spectra for time of MMRPC without any slew correction.

Regarding the time measurements, the mean time viz., $(t_{left} + t_{right})/2$, of the signals taken from both end of a MMRPC strip was considered. Thus time measurements, for the involved strips were obtained from the arithmetic mean of the time obtained from the signals delivered from both end of a strip of the MMRPC. Figure 10 shows a two-dimensional plot of time distribution of the MMRPC against the average charge deposited on a particular single strip. It is observed that time information for signals with low amplitude differs from that of the signals with higher amplitude. The leading edge discrimination technique has been used in extracting the time information by

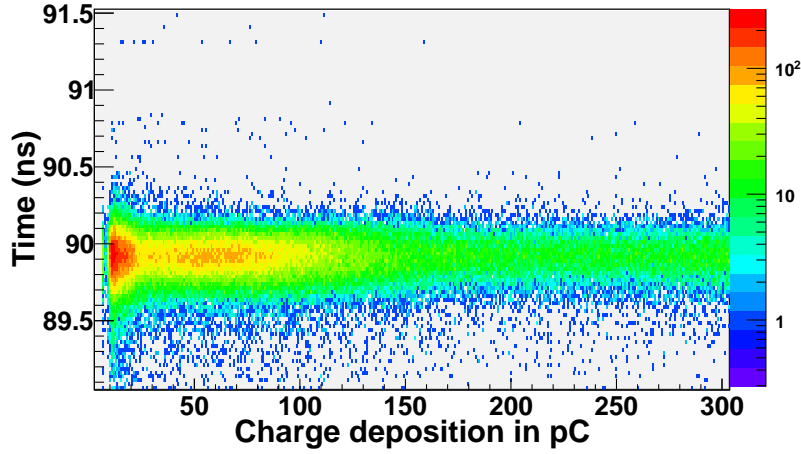


Figure 12. Two dimensional plot for time of MMRPC after slew-correction (using our developed method) against deposited charge on a single strip.

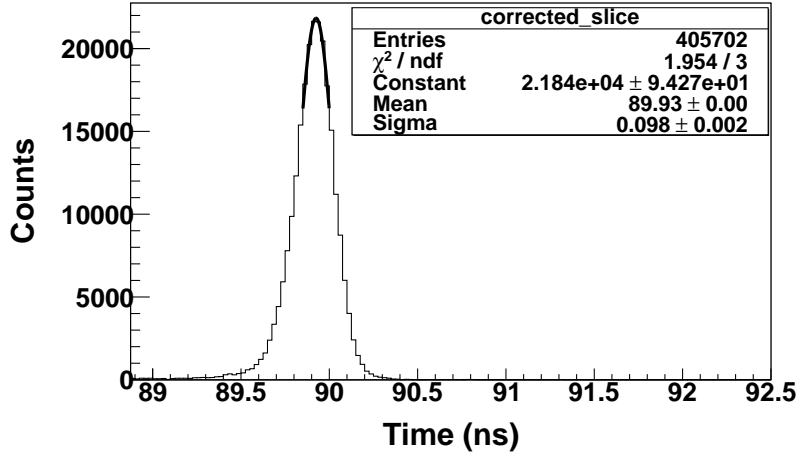


Figure 13. Time of MMRPC after slew-correction (considering our developed method).

the FOPI cards [29]. Off-line correction of this walk in the time measurement is called the slew correction. The time resolution (σ_t) without the slew correction, as shown in Figure 11, is less than 150 ps. This is consistent with our previous measurements using the same detector with the cosmic muon at SINP laboratory [22]. The Slew correction in the time measurement was performed using two different methods - our developed method and the conventional curve fitting method which are in general used for timing of MRPC. In our method, the QDC spectra was divided into slices of sufficient small charge distribution width. The measured peak positions in the time spectra were aligned corresponding to each of this QDC slices through an iteration process. Figure 12 shows the two dimensional plot of the time distribution of MMRPC after the slew correction against the charge deposited in a single strip. The obtained time resolution (σ_t) for all good events (as shown in Figure 13) after this slew correction is 98.0 ± 3 ps. Considering the correction for electronics

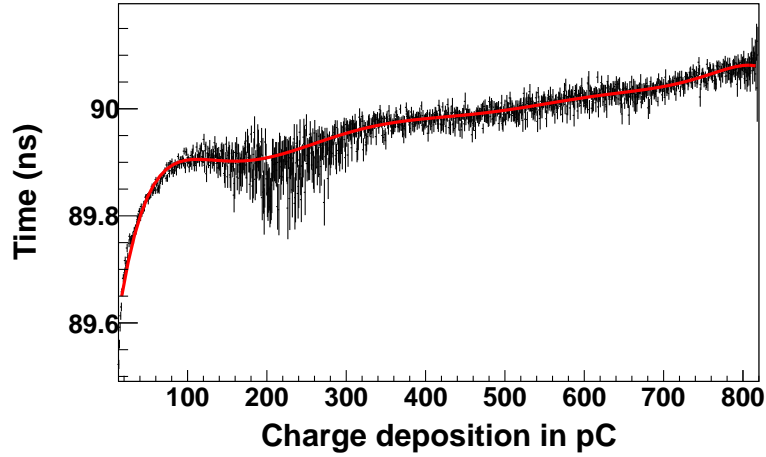


Figure 14. 2D-Profile histogram corresponding to the time distribution of MMRPC (without the slew correction) Vs.charge deposited on a single strip.

and reference trigger ($\sigma_t \sim 35$ ps) the obtained timing resolution was 91.5 ± 3 ps. In the standard method, a profile histogram corresponding to the two dimensional plot of Figure 10 was generated. The profile was then fitted with a correct curve. In principle the region of the profile with lower charge deposition should be fitted with an exponential function while for the rest part with higher charge deposition should be fitted with a straight line. The best fitted curve was obtained by fitting the two region with two multi-order polynomial. Figure 14 shows the fitted two dimensional profile histogram. The idea of the slew correction is to linearize the profile through different iterations. Figure 15 shows the same 2-Dimensional plot after the slew correction using the conventional curve fitting method. The time resolution (σ_t) obtained in this method after slew correction is 111.3 ± 3.0 ps (Figure 16). The variation of time resolution (without the slew correction) against bias voltage has been shown in Figure 17. A trend of improving time resolution with increasing MMRPC bias voltage was observed. The time resolution improves with increasing bias voltage and reaches a minima at bias voltage ~ 7.5 kV. Figure 18 shows the same plot but after the slew correction. The slew correction in this case was done using curve fitting method. Better time resolution of 79.6 ± 1.0 ps was obtained by considering of events from a single strip of the detector.

The Position resolution (σ_x , σ_y) along the strip was measured from the difference in time measurement from both end of a strip. The Data was considered for which the beam spot was positioned 7.5 cm and 15 cm away from the center along the length of strip-4. The difference in time from the two TDCs at both end of a strip reflected in the signal velocity through the anode strip. Considering signal velocity (13.8 cm/ns) and time resolution (100ps) the measured position resolution (σ_x) of MMRPC along the strip was around 2.8 ± 0.6 cm. The strip width being 2 cm, the position resolution (σ_y) across the strip is 0.58 cm.

4. Discussion

In order to understand the operational characteristics of the MMRPC detector, the time resolution

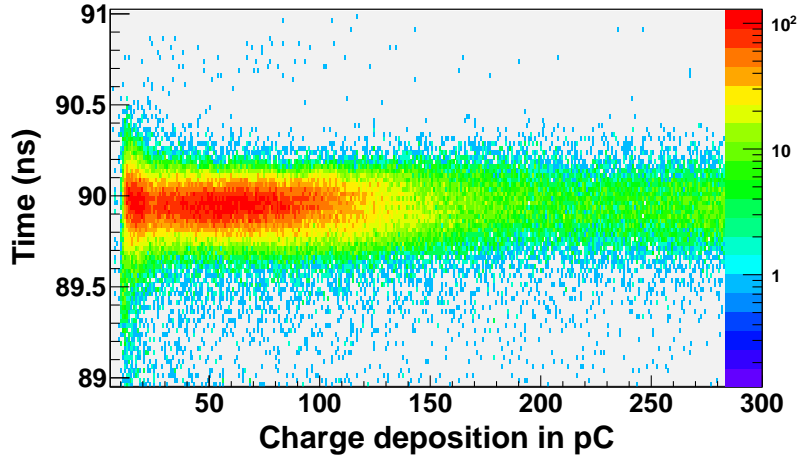


Figure 15. Plot for time distribution of MMRPC after the slew-correction using conventional curve fitting method against deposited charge on a single strip.

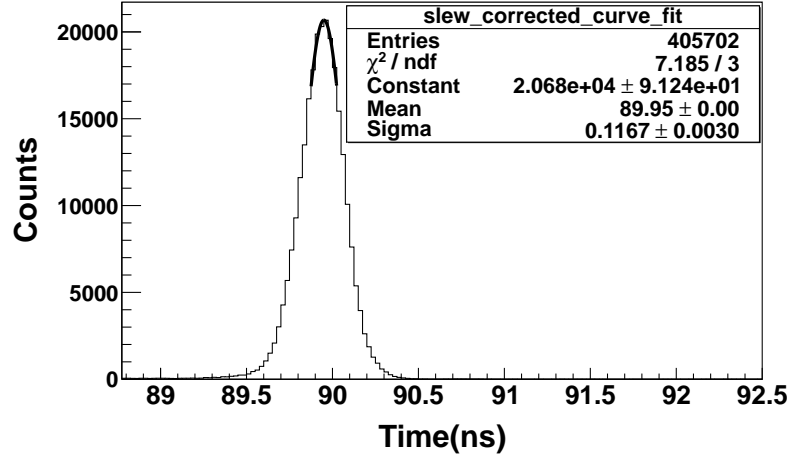


Figure 16. Time distribution of MMRPC after the slew-correction using the curve fitting method.

and absolute efficiency of the detector was measured by considering of events selected according to different schemes or trigger conditions. In one such scheme, events were selected for which only one strip has fired. The two dimensional plot for time distribution of MMRPC against deposited charge on the corresponding strip looked clean as shown in Figure 19. The time resolution (σ_t) corresponding to these events before and after slew-correction were respectively, 129 ps and 79.6 ps.

In the two dimensional spectra for ToF of MMRPC (without slew correction) against deposited charge on a single strip, intense smaller charge distribution was observed (Figure 21). Projection on the time axis with a graphical cut (Figure 22) on this intense smaller charge shows a time resolution (σ_t) of 56.5 ± 1.3 ps (without slew correction) (Figure 23). Thus in expense of efficiency, better timing resolution can be obtained in MMRPC. This analysis shows that graphical cut method

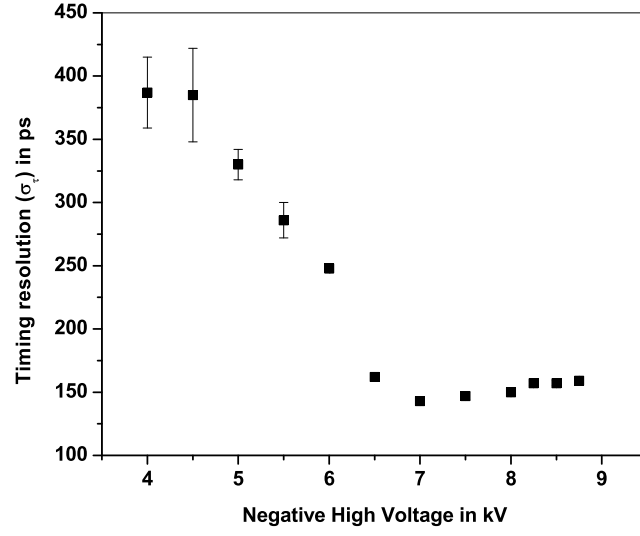


Figure 17. Variation of the time resolution (σ_t) of MMRPC against the bias voltage.

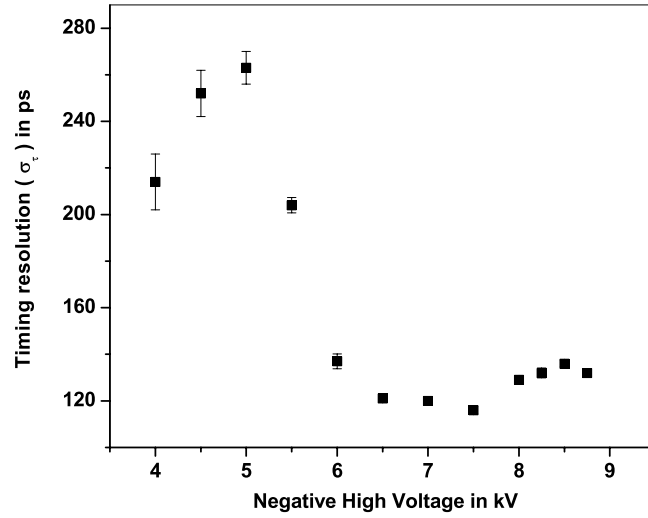


Figure 18. Variation of the time resolution (σ_t) against the bias voltage of MMRPC after the slew correction using the curve fitting method.

of analysis can be used in the analysis algorithm to avoid slew correction. Table 1 shows the time resolution and efficiency of our developed MMRPC detector with different analysis methods.

It is interesting to note that response mechanism of present MMRPC is mainly of avalanche mode but in the two dimensional plot for time distribution of MMRPC against deposited charge on

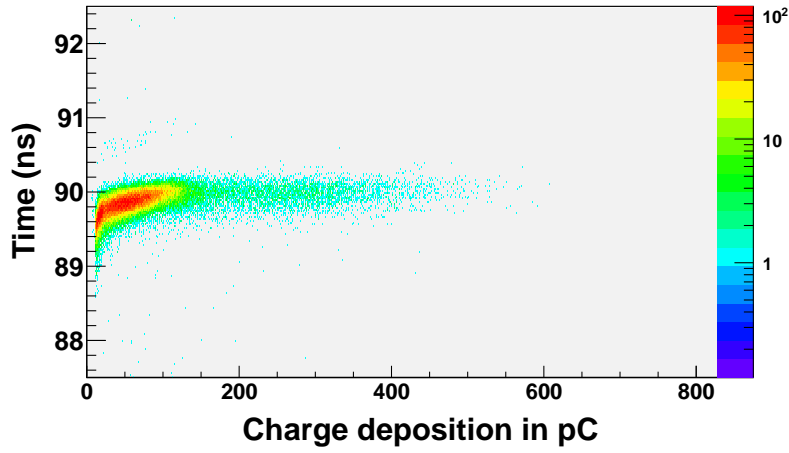


Figure 19. Time distribution of MMRPC (without slew correction) against the deposited charge on a strip for the events hitting only one strip at a time.

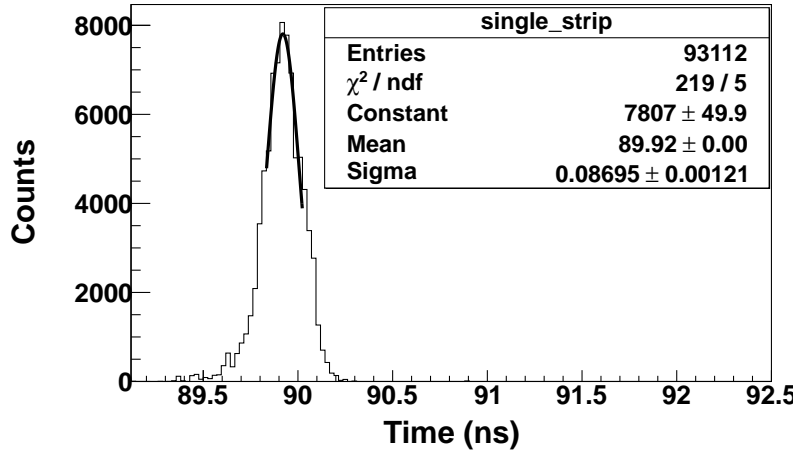


Figure 20. Time of MMRPC for events hitting only one strip.

a single strip, three patches at lower, intermediate and higher charge depositions can be observed (Figure 21). In order to understand the causes of these charge distributions, three different graphical cuts were made corresponding to the three different charge distribution. Relative contributions of the three patches were determined from these three cuts. That was continued for data corresponding to different bias voltages of MMRPC. Figure 24 shows the efficiency of the three patches with increasing bias voltage. It was observed that the contribution for the first patch at lower charge deposition dominates at lower bias voltage. It reaches a maxima at $\sim 6.5\text{KV}$ and then decreases. The patch at lower charge deposition may be due to the avalanche mechanism in the detector. The contribution due to the second and third patches increases with increasing bias voltage. These two patches at higher charge deposition may be due to two different streamers dominating at higher electric field. The efficiency of the three patches at different charge deposition was also studied with

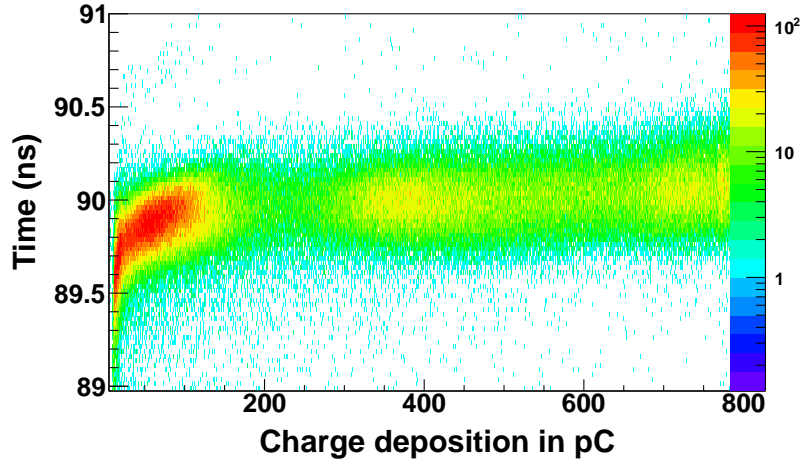


Figure 21. Two dimensional plot for the time distribution of MMRPC against the charge deposited on a strip showing three patches at different charge deposition.

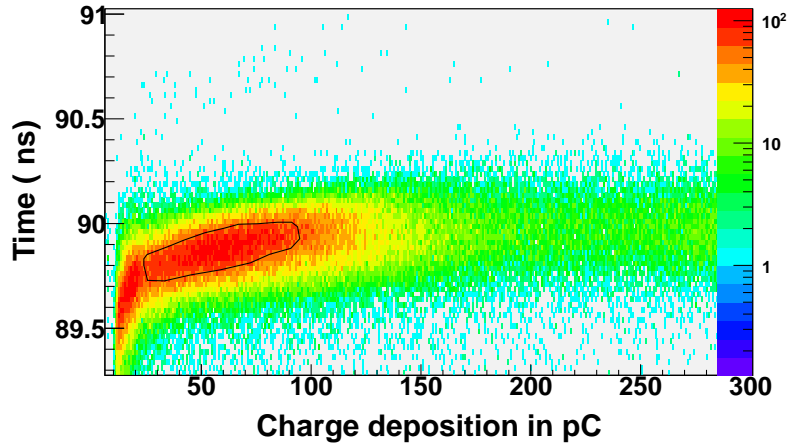


Figure 22. Two dimensional plot for the time distribution of MMRPC against the deposited charge, showing the graphical cut.

the variation in trigger rate of the beam. Figure 25 shows the contributions of different operational mechanism of the MMRPC detector at different event rate for a fixed bias voltage. It is interesting to note that at higher event rates streamer mode of operation decreases whereas avalanche mode of operation dominates for a particular bias voltage. Figure 26 shows a plot of the observed event rate in MMRPC against the actual event rate. As seen from figure 25 the system does not show any significant dead time upto 800 Hz. Recently, it has been shown by several groups [31, 32] that high detection efficiency with good timing resolution (around 90 %) can be obtained for response of electrons with higher events rate (more than few kHz) using MRPC with low resistivity doped glass.

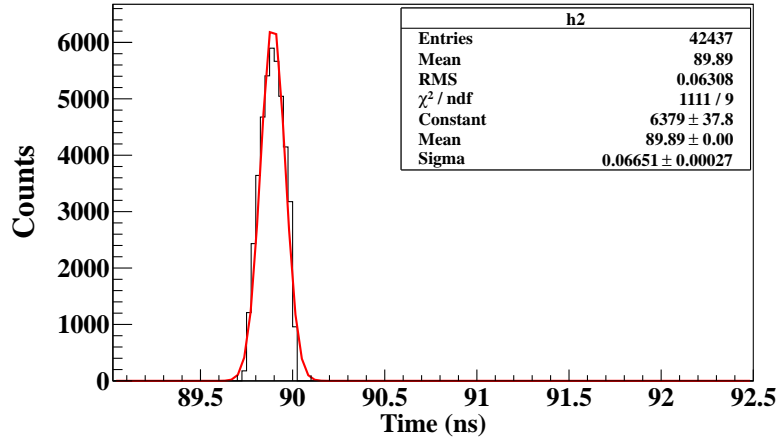


Figure 23. Time distribution of MMRPC corresponding to graphical cut.

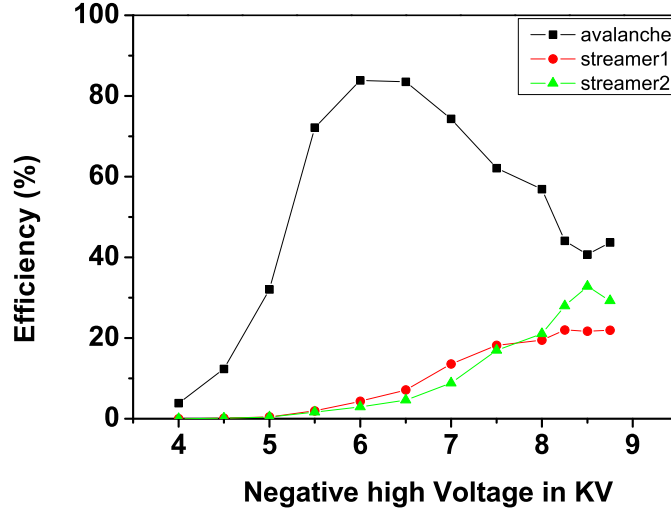


Figure 24. Contribution of the avalanche and streamers mode of response at different bias voltage of MMRPC.

5. Summary

A prototype of Multi-strip Multi-gap Resistive Plate chamber (MMRPC) with active area $40 \text{ cm} \times 20 \text{ cm}$ has been developed at SINP, Kolkata. Detailed response of the developed detector was studied using the pulsed electron beam from ELBE at Helmholtz-Zentrum Dresden-Rossendorf. The response of SINP developed MMRPC with different controlling parameters has been described in details. The obtained time resolution (σ_t) of the detector after slew correction was $91.5 \pm 3 \text{ ps}$. Position resolution measured along (σ_x) and across (σ_y) the strip was $2.8 \pm 0.6 \text{ cm}$ and 0.58 cm , respectively. The measured absolute efficiency of the detector for minimum ionizing particle like

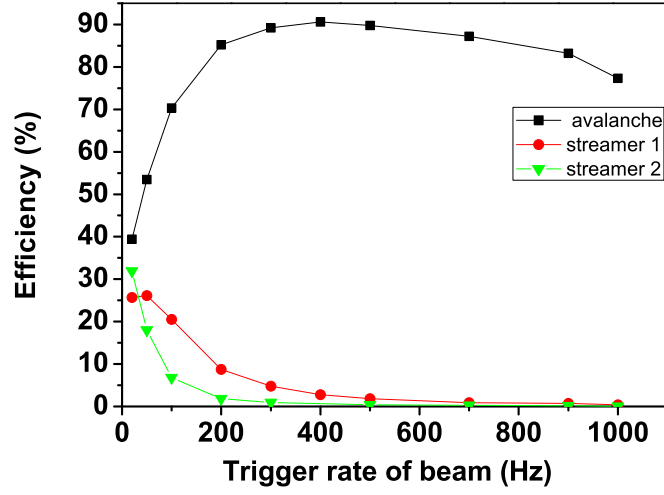


Figure 25. Contribution of the avalanche and streamers mode of response at different trigger rate for a fixed bias voltage.

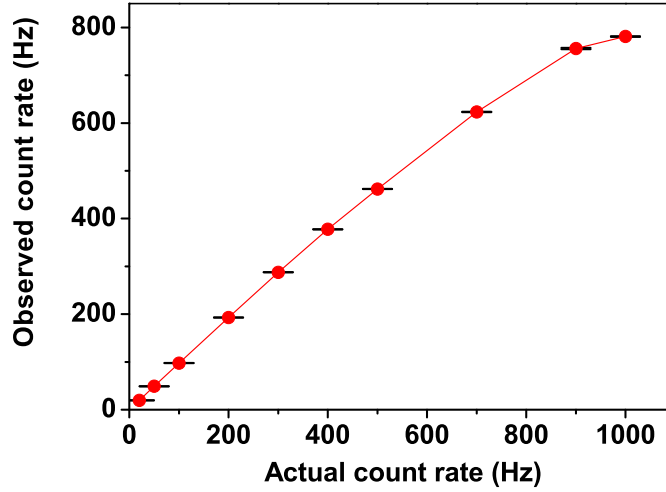


Figure 26. Plot of observed event rate of MMRPC against actual event rate.

electron was 95.8 ± 1.3 %. Better timing resolution of the detector of 79.6 ± 3.5 ps was obtained by restricting to the events hitting only a single strip. It was further observed that under special consideration of events using graphical cut at smaller charge distribution, slew correction in time resolution becomes non-essential. The efficiency corresponding to these events though decreases but timing resolution as good as 53.2 ± 1.3 ps can be obtained. The response of the detector was mainly in avalanche mode but a few percentage of streamer mode response was also observed.

Table 1. Time resolution (σ_t) of Multi-strip Multi-gap Resistive Plate Chamber at various conditions and constraints

Case	Analysis methods	Time resolution (σ_t) in ps for	
		1 σ fitting	2 σ fitting
1	slew-correction by conventional curve fitting method	111.3 \pm 3.0	113.8 \pm 1.0
2	slew-correction by our developed method	91.5 \pm 2.7	95.6 \pm 0.5
3	for events hitting only strip no. 4 & slewing	79.6 \pm 1	85.2 \pm 0.9
4	making graphical cut before slew correction	56.5 \pm 1.3	

Acknowledgments

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